Toll Modeling Enhancements (SACOG)

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Topics

- Introduction to toll modeling
- Network coding
- Toll optimization algorithm
- Interpreting results

Intro To Toll Modeling

Methods of Modeling Tolls

- As part of mode choice
  - Consistent choice treatment (+)
  - Alternative-specific constants (+)
  - Can cause issues with logsums (-)
  - Inconsistent with assignment paths (-)
- As part of route choice
  - Eliminates mode\route choice problem (+)
  - Can’t use alternative-specific constants (-)
  - Previously required average values of time (computational constraints) but can now use segmented values of time

What Does the Auto Utility Look Like?

$$Utility_{ij} = \alpha \times Time_{ij} + \beta \times \left[Cost_{ij} / \left(I^{e} \times O^{f}\right)\right]$$

From skims: If toll is least-cost path, represents toll time and cost; else non-toll path

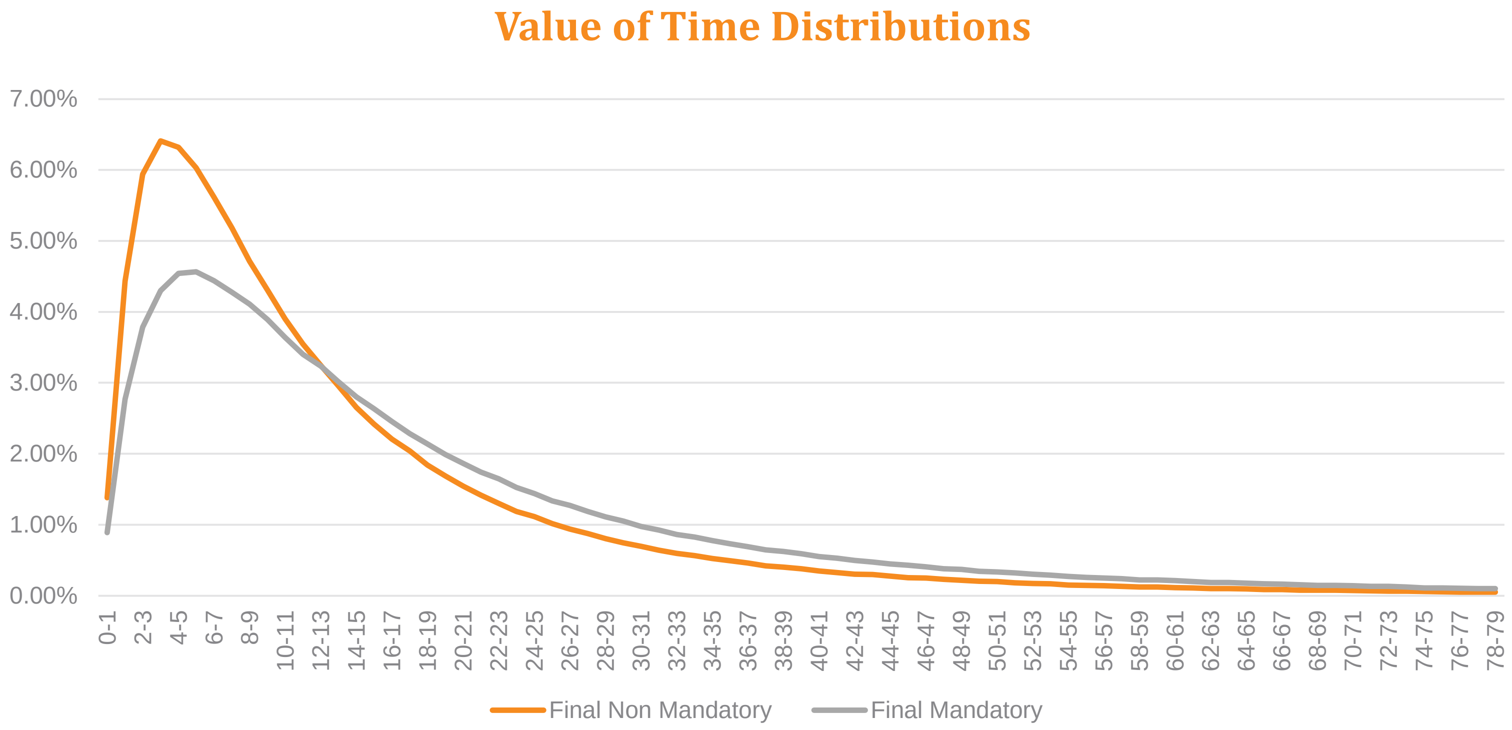
where:

α is a log-normally distributed random parameter representing unobserved user heterogeneity with respect to travel time sensitivity
β is the travel cost coefficient

I^{e} captures the effect of income (I) on travel cost sensitivity
O^{f} captures the effect of auto occupancy on travel cost sensitivity

Value of time = $\alpha \left(I^{e} \times O^{f}\right) / \beta$

Revisions to the value-of-time distributions



Several trials were run with different values of standard deviation and compared against distributions from other regions. A standard deviation of 0.85 was selected for both mandatory and non-mandatory trips in the current version. These plots more closely match the results of several stated preference surveys conducted by RSG over the past several years.

Revisions to the value-of-time distributions

Value of Time (VOT) bins were created using the 33rd, 66th and 90th percentile values of the VOT for all trips. The corresponding dollar amounts were $7.25, $16.85 and $38.80 per hour respectively.

VOT BINS

Low = 60/7.25 = 8.28 min/$

Mid = 60/16.85 = 3.56 min/$

High = 60/38.8 = 1.55 min/$

Level of Service Skims

The model determines the least impedance path based on the following equations -

```
lw.imped_da = li.time_1 + (li.tollda*tollivot + lw.AOCost*@ivot@)
lw.imped_s2 = li.time_1 + (li.tolls2*tollivot + lw.AOCost*@ivot@) / HOV2Divisor
lw.imped_s3 = li.time_1 + (li.tolls3*tollivot + lw.AOCost*@ivot@) / HOV3Divisor
```

where

li.time – travel time in the link

li.tollda – drive alone toll in the link

lw.AOCost – auto operating cost

tollivot – inverse value of time (min/$)

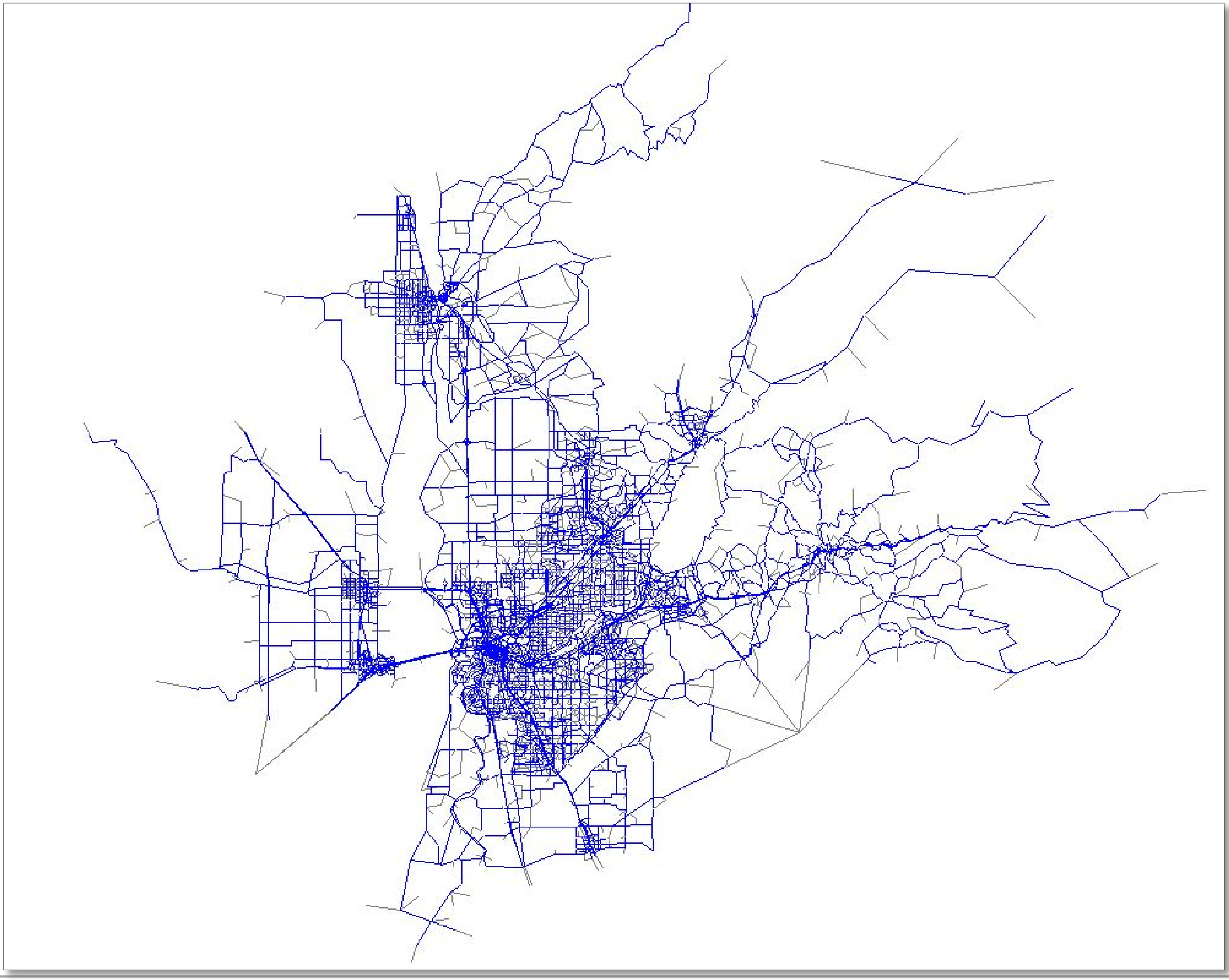
A total of 243 skim matrices are created for 3 VOT classes (low, mid, high), 3 occupancy classes (da, s2, s3+), 3 measures of level of service (time, distance and toll) and 9 time periods.

Number of Skim Matrices = 3 * 3 * 3 * 9 = 243

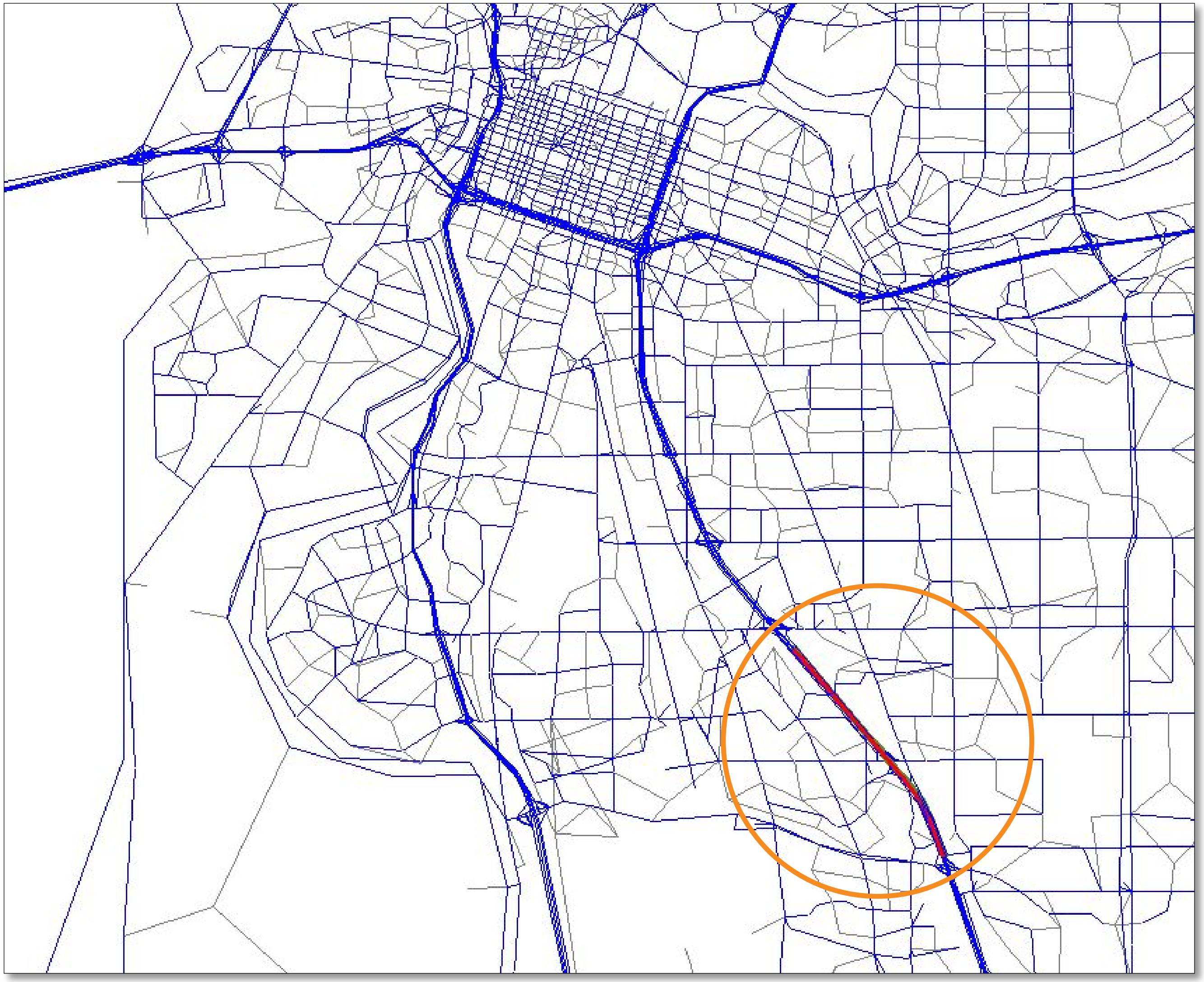
Skims are ‘matched’ to VOT of traveler in DaySim

Coding Toll Facilities

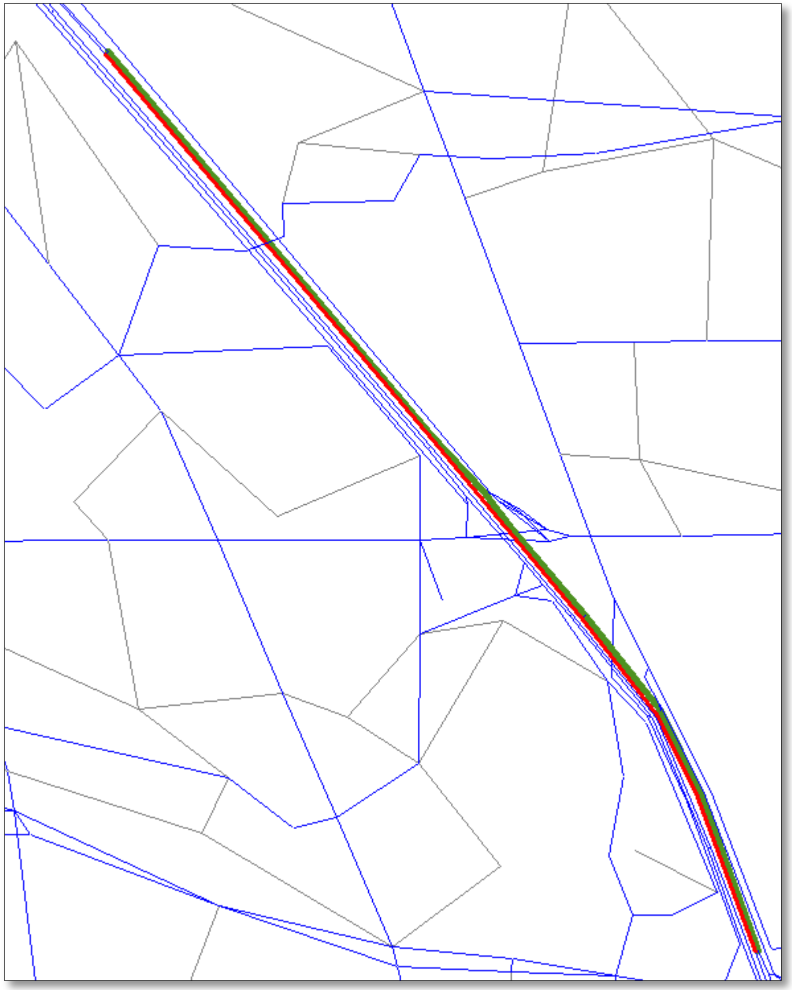
SACOG Network



Toll Segment Coding



Toll Segment Coding



Toll Segment
Parallel General Purpose Segment

- The lengths of the toll segment and the parallel general purpose (GP) segment should be equal so that the model can compare the travel times between the two.
- This allows the model to compute the time savings a traveler will get by driving in the toll segment as opposed to the general purpose segment.
- If the lengths are different, the model would compare travel times of segments of different lengths and the time savings will not be representative of reality.

Occupancy Restrictions and Toll Lane Identification

Toll Segment: Segments of freeway intended for tolling are identified using a new link level attribute (TOLLID). This allows the model to identify the tolled lanes and the parallel general purpose lanes with another link attribute (GPID).

Defining the toll segments is necessary to compute the time savings for driving in the toll lanes compared to general purpose lanes. This allows the model to calculate the value-of-time toll. The USECLASS field is necessary to identify HOV/HOT facilities.

Network Field: **USECLASS**

- ❑ USECLASS = 0 corresponds to a general purpose lane
- ❑ USECLASS = 2 corresponds to a shared ride 2+ facility
- ❑ USECLASS = 3 corresponds to a shared ride 3+ facility

Network Field: **GPID** and **TOLLID**

- ❑ GPID = 1 corresponds to a general purpose lane
- ❑ TOLLID = 1 corresponds to a toll lane

Note: Toll costs coded in tolls.csv (see next slides), not on network!

What is the difference between a HOT lane and a Toll Road

HOT Lane: A high-occupancy toll (HOT) lane is a type of traffic lane or roadway that is available to high-occupancy vehicles and other exempt vehicles without charge; other vehicles (e.g. SOV) are required to pay a variable fee that is adjusted in response to demand. (Wikipedia)

Toll Road: A toll road is a facility where all vehicles irrespective of occupancy class on all lanes are tolled for usage.

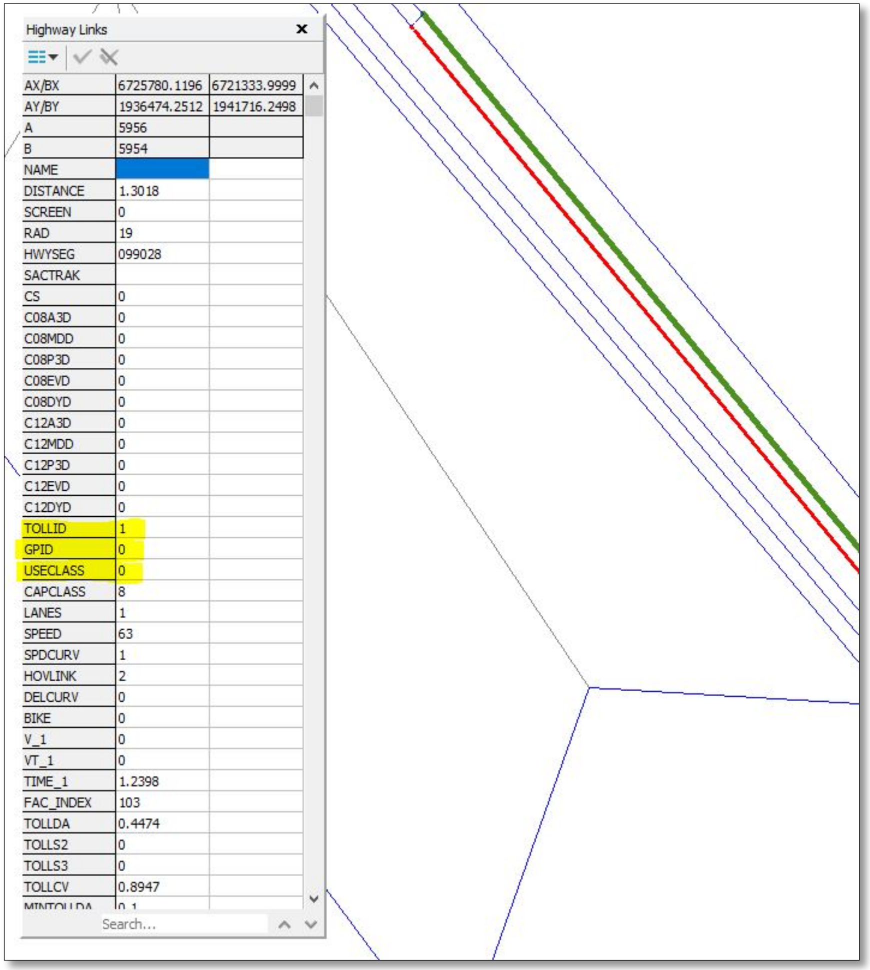
How To Code:

HOT Lane: The user should set the value of the TOLLID variable to greater than 0 for the toll lanes and GPID greater than 0 for the parallel general purpose lanes.

Toll Road: The user should code a TOLLID > 0 for all lanes in the highway segment intended for tolling.

Example: Coded HOT Lane

HOT Lane

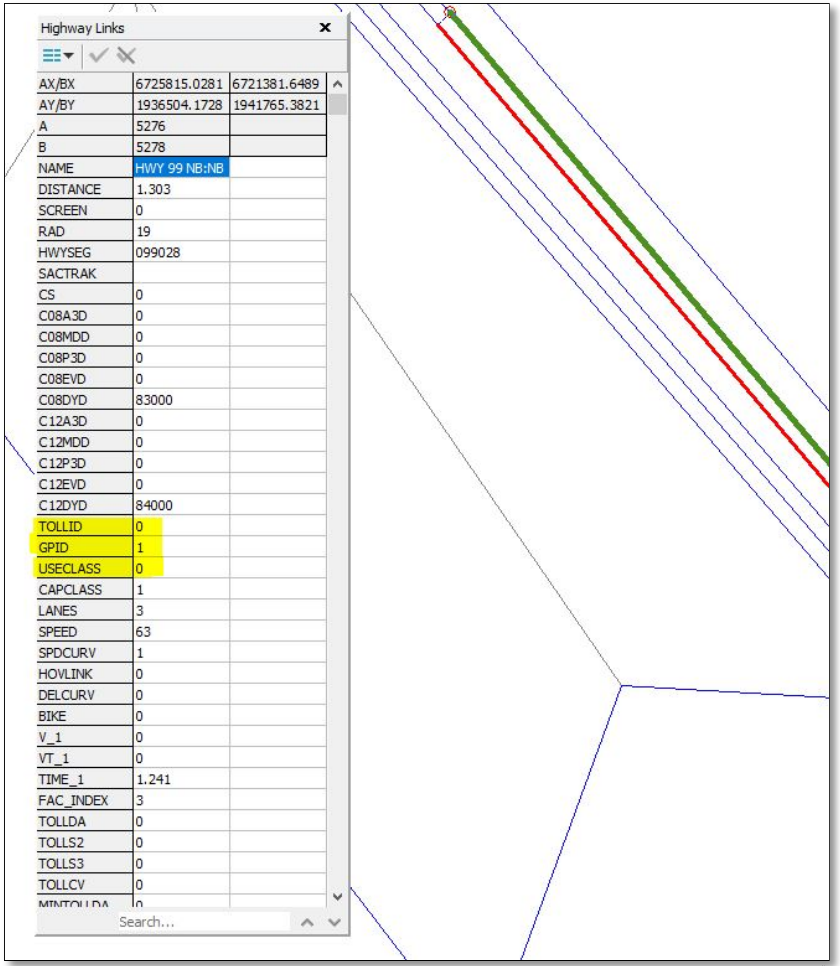


Highway Links

AX/BX	6725780.1196	6721333.9999
AY/BY	1936474.2512	1941716.2498
A	5956	
B	5954	
NAME		
DISTANCE	1.3018	
SCREEN	0	
RAD	19	
HWYSEG	099028	
SACTRAK		
CS	0	
C08A3D	0	
C08MDD	0	
C08P3D	0	
C08EVD	0	
C08DYD	0	
C12A3D	0	
C12MDD	0	
C12P3D	0	
C12EVD	0	
C12DYD	0	
TOLLID	1	
GPID	0	
USECLASS	0	
CAPCLASS	8	
LANES	1	
SPEED	63	
SPDCURV	1	
HOVLINK	2	
DELCURV	0	
BIKE	0	
V_1	0	
VT_1	0	
TIME_1	1.2398	
FAC_INDEX	103	
TOLLDA	0.4474	
TOLLS2	0	
TOLLS3	0	
TOLLCV	0.8947	

Search...

GP Lane



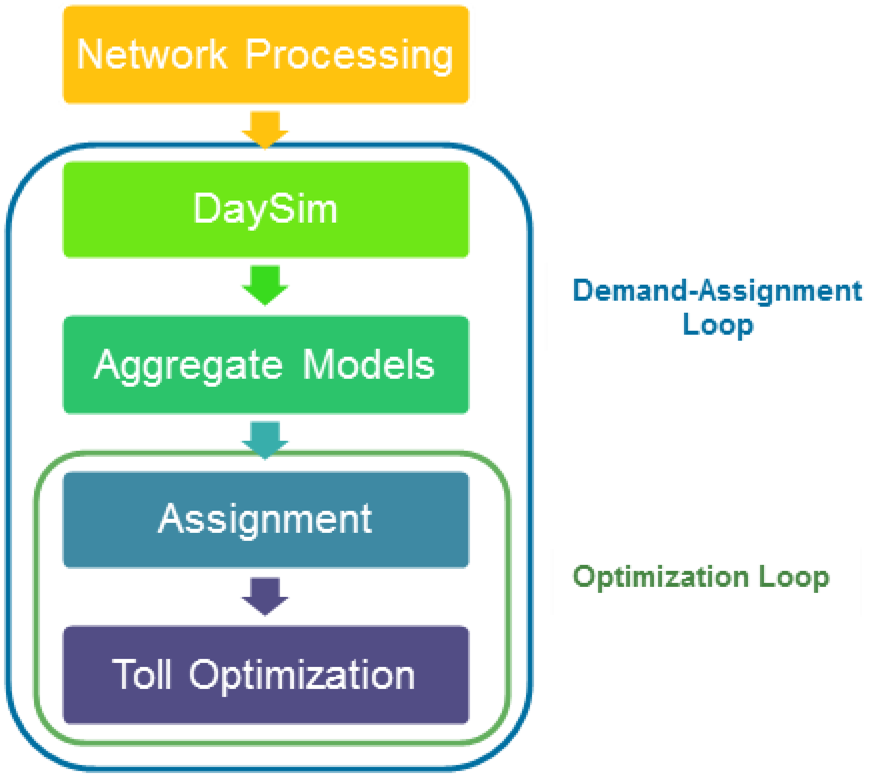
Highway Links

AX/BX	6725815.0281	6721381.6489
AY/BY	1936504.1728	1941765.3821
A	5276	
B	5278	
NAME	HWY 99 NB:NB	
DISTANCE	1.303	
SCREEN	0	
RAD	19	
HWYSEG	099028	
SACTRAK		
CS	0	
C08A3D	0	
C08MDD	0	
C08P3D	0	
C08EVD	0	
C08DYD	83000	
C12A3D	0	
C12MDD	0	
C12P3D	0	
C12EVD	0	
C12DYD	84000	
TOLLID	0	
GPID	1	
USECLASS	0	
CAPCLASS	1	
LANES	3	
SPEED	63	
SPDCURV	1	
HOVLINK	0	
DELCURV	0	
BIKE	0	
V_1	0	
VT_1	0	
TIME_1	1.241	
FAC_INDEX	3	
TOLLDA	0	
TOLLS2	0	
TOLLS3	0	
TOLLCV	0	

Search...

Toll Optimization Algorithm

Toll Optimization



Input Tolls File

- Create a tolls.csv file that contains toll values for each toll segment by time periods.

Fac. Index	Seg	Per	Fac. Type	Adjust	Toll DA	Toll S2	Toll S3	Toll CV	Min DA	Min S2	Min S3	Min CV	Max DA	Max S2	Max S3	Max CV
101	1	1	2	1	1	0	0	2	0.1	0	0	0.2	30	0	0	30
201	2	1	2	1	1	0	0	2	0.1	0	0	0.2	30	0	0	30
301	3	1	2	1	1	0	0	2	0.1	0	0	0.2	30	0	0	30
401	4	1	2	1	1	0	0	2	0.1	0	0	0.2	30	0	0	30

Field Descriptions

Facility Index: A combined index to represent segment and period (segment*100+period)

Segment: The toll segment

Period: Period of the day

Facility Type: 1=Toll Road, 2=HOT lane

Adjust: Binary variable indicating whether to adjust this segment's toll cost in the toll optimization algorithm

Toll_*class*: Initial toll for different occupancy classes (DA, S2, S3, CV)

Min_*class*: Minimum toll for different occupancy classes (DA, S2, S3, CV)

Max_*class*: Maximum toll for different occupancy classes (DA, S2, S3, CV)

Toll Optimization Algorithm

- The model computes the travel times in the tolled links (TOLLID > 0) and the parallel general purpose links (GPID > 0) and calculates the difference i.e. the time savings in the tolled facility.
- Time savings is then multiplied by the average value of time across all travelers and to obtain the value-of-time (VOT) toll.
- The segment level toll is then apportioned to individual links in the toll segment.

Toll Optimization Algorithm

- The max volume to capacity (v/c) ratio among all tolled links is calculated and compared against a user defined maximum (0.8 set by RSG)

```
maxvoc_allowed = 0.8
```

- If the max v/c ratio exceeds the user defined limit, the VOT toll is then multiplied by a user defined factor (2 set by RSG) to price out some vehicles from the tolled facility.

```
toll_incr = 2.0  ; a multiplicative factor on initial toll in case the toll is already
                   higher than the VOT toll
```

- This process is repeated until a user defined convergence condition is achieved (change_thresh < $0.5 set by RSG).

```
_maxTollChange = 0
change_thresh = 0.50 ; If toll doesn't change by more than this amount stop
                       iterating
```

What can the users control?

- Inputs to the tolls.csv file –
  - Initial tolls
  - Minimum tolls
  - Maximum tolls

  The user can specify different initial, min and max tolls for different segments (e.g. different highways)

- Within the script –
  - The v/c threshold (currently set to 0.8) using the `maxvoc_allowed` parameter. This parameter lets the user control the desired level of service in the tolled facilities.
  - The optimization loop exit threshold (currently set to 0.5) using the `change_thresh` parameter. This allows the user to set the convergence criteria and has implications in model runtime. A larger value means quicker convergence and lower runtime, but less accuracy in the optimized tolls.
  - The user can also control the number of toll optimization loops to run in the model using the `toop` parameter.
  - The toll increment factor (currently set to 2.0) using the `toll_incr` parameter. This allows the user to control how tolls should increase in the facilities should the volume exceed the desired v/c ratio.

Example Coding Instructions

Coding a new HOT lane on SR-99

1. Open the input base network in cube (*2016_base.net*)
2. Select each link within the new toll segment and set TOLLID = 5
3. Select each link parallel to the toll segment and set GPID = 5
4. Check to make sure that USECLASS on HOT lanes is set to 0. Usually, HOV lanes have USECLASS = 2
5. Save and close the network
6. Open the input *tolls.csv* file
7. Add a row with input toll information such as segment number, initial toll, min toll and max toll
8. One entry for each time period is required if the segment is tolled differently at different times of day
9. Save and close the csv file
10. Open the Cube script for the model (*SACSIM_ModelRun_July2018.s*)
11. Change any user defined parameters in the script
12. Save the script
13. Open Cube Voyager, select the script and run the model

Results

Output Files and Fields

During each optimization loop, results are written out to files named **nextToll.*per*.*loop*.csv** which contain –

- the travel times in toll and gp segments
- new values of tolls
- the volume in the most congested link in the segment.

The following tables show the information contained in each output file during the optimization procedure.

Toll Optimization Loops in Period 3 (h09)

toll loop	segment	tollsegtime	gpsegtime	timesavings	vottoll	maxvoc	da	s2	s3	cv	maxtollchange
Loop 1	1	3.21	3.33	0.12	0.04	0.79	0.11	0	0	0.16	0.01
	2	3.33	3.56	0.24	0.07	0.69	0.11	0	0	0.16	0.01
	3	4.78	6.07	1.29	0.38	**0.79**	0.61	0	0	0.92	0.23
	4	4.09	4.24	0.15	0.04	0.76	0.11	0	0	0.16	0.23
Loop 2	1	3.2	3.35	0.15	0.04	0.79	0.11	0	0	0.16	0.01
	2	3.33	3.56	0.24	0.07	0.7	0.11	0	0	0.16	0.01
	3	4.9	5.85	0.95	0.28	**0.85**	0.92	0	0	1.37	0.31
	4	4.07	4.25	0.18	0.05	0.74	0.11	0	0	0.16	0.31
Loop 3	1	3.18	3.36	0.17	0.05	0.77	0.11	0	0	0.16	0.01
	2	3.33	3.56	0.23	0.07	0.69	0.11	0	0	0.16	0.01
	3	4.75	6.11	1.36	0.4	**0.78**	0.66	0	0	0.99	0.26
	4	4.09	4.25	0.17	0.05	0.75	0.11	0	0	0.16	0.26
Loop 4	1	3.2	3.35	0.15	0.04	0.78	0.11	0	0	0.16	0.01
	2	3.33	3.56	0.24	0.07	0.7	0.11	0	0	0.16	0.01
	3	4.89	5.9	1.01	0.3	**0.84**	0.99	0	0	1.49	0.33
	4	4.08	4.26	0.18	0.05	0.75	0.11	0	0	0.16	0.33
Loop 5	1	3.2	3.34	0.15	0.04	0.78	0.11	0	0	0.16	0.01
	2	3.33	3.56	0.24	0.07	0.7	0.11	0	0	0.16	0.01
	3	4.73	6.09	1.36	0.4	**0.78**	0.7	0	0	1.04	0.29
	4	4.08	4.26	0.18	0.05	0.75	0.11	0	0	0.16	0.29

Toll Optimization Loops in Period 3 (h09)

Let's look at how the toll is adjusted for segment 3 in loop 2. In the first loop, it is observed that the maxvoc is less than the threshold (0.8) in all segments. In the second loop, maxvoc for segment 3 (0.85) increased above the threshold, so the algorithm incremented the initial toll (previous toll) by a factor (2.0) and took an average of the incremented toll and the previous toll for setting the new toll value.

for loop 2,

initial toll (previous toll from loop 1) = 0.61

vot toll = 0.28

max voc = 0.85

since (initial toll > VOT toll) and (max voc > threshold)

nextToll = initial toll * 2.0 = 0.61 * 2.0 = 1.22

avgToll = (nextToll + initial toll)/2 = (1.22 + 0.61)/2 = 0.92

The purpose of incrementing the toll was to bring the v/c ratio below the threshold. In the next loop (loop 3), it is observed that v/c ratio is down to 0.78 for segment 3.

The optimization loops continue until this condition is met or the user defined maximum number of loops is reached.

Volume after loop 5 in Period 3 (h09)

	Segments	DA_1	CV2_1	CV3_1	S2_1	S3_1
Low VOT	1	0	0	0	218.95	75.07
	2	0	0	0	145.06	49.39
	3	0	0	0	256.86	89.08
	4	0	0	0	236.29	78.5
	Segments	DA_2	CV2_2	CV3_2	S2_2	S3_2
Med VOT	1	33.23	5.35	0.76	345.5	148.67
	2	0	0	0	206.81	89.04
	3	24.39	4.28	0.69	348.22	152.3
	4	0	0	0	272	121.69
	Segments	DA_3	CV2_3	CV3_3	S2_3	S3_3
High VOT	1	230.79	90.3	2.77	220.49	129.09
	2	280.92	276.66	17.27	105.86	65.17
	3	210.91	91.33	2.02	207.05	125.6
	4	210.17	232.48	1.4	141.26	90.16

What happens when HOV demand exceeds the capacity of the toll facility?

Tolls keeps increasing until they reach the maximum toll and SOVs are priced out of the tolled facilities.

Toll Optimization Loops in Period 2 (h08)

toll loop	segment	tollsegtime	gpsegtime	timesavings	vottoll	maxvoc	da	s2	s3	cv	maxtollchange
Loop 1	1	3.95	5.92	1.97	0.58	1	30	0	0	30	0
	2	3.4	3.79	0.38	0.11	0.79	0.14	0	0	0.21	0.03
	3	6.81	11.36	4.55	1.35	1.1	30	0	0	30	0.03
	4	4.02	4.62	0.6	0.18	0.76	0.28	0	0	0.43	0.11
Loop 2	1	3.95	5.94	1.99	0.59	1	30	0	0	30	0
	2	3.43	3.76	0.33	0.1	0.81	0.21	0	0	0.32	0.07
	3	6.81	11.28	4.47	1.33	1.1	30	0	0	30	0.07
	4	4.11	4.55	0.44	0.13	0.8	0.21	0	0	0.31	0.08
Loop 3	1	3.96	5.93	1.97	0.58	1	30	0	0	30	0
	2	3.38	3.83	0.45	0.13	0.77	0.17	0	0	0.26	0.04
	3	6.8	11.28	4.48	1.33	1.1	30	0	0	30	0.04
	4	4.17	4.5	0.33	0.1	0.81	0.32	0	0	0.47	0.11
Loop 4	1	3.95	5.93	1.97	0.59	1	30	0	0	30	0
	2	3.4	3.79	0.39	0.12	0.79	0.14	0	0	0.21	0.03
	3	6.8	11.27	4.47	1.33	1.1	30	0	0	30	0.03
	4	4.07	4.57	0.49	0.15	0.78	0.23	0	0	0.35	0.09
Loop 5	1	3.95	5.93	1.97	0.59	1	30	0	0	30	0
	2	3.43	3.76	0.33	0.1	0.81	0.21	0	0	0.32	0.07
	3	6.81	11.34	4.54	1.35	1.1	30	0	0	30	0.07
	4	4.15	4.52	0.37	0.11	0.81	0.35	0	0	0.52	0.12

Although the v/c ratio on segments 1 and 3 are above 0.8, the model cannot reduce the volumes since toll has reached it's maximum value. You'll notice in the next slide that all DA and CV demand has already been priced out, but too many S2 and S3+ is using the facility.

Volume after loop 5 in Period 2 (h08)

	Segments	DA_1	CV2_1	CV3_1	S2_1	S3_1
Low VOT	1	0	0	0	328.54	124.46
	2	0	0	0	136.94	50.49
	3	0	0	0	407.96	147.54
	4	0	0	0	155.35	54.69
	Segments	**DA_2**	**CV2_2**	**CV3_2**	**S2_2**	**S3_2**
Med VOT	1	0	0	0	552.44	240.78
	2	0	0	0	174.83	93.22
	3	0	0	0	565.98	261.62
	4	0	0	0	193.2	98.79
	Segments	**DA_3**	**CV2_3**	**CV3_3**	**S2_3**	**S3_3**
High VOT	1	0	0	0	487.55	270.25
	2	281.89	413.67	45.36	100.35	67.12
	3	0	0	0	529.19	288.39
	4	282.41	439.02	0	106.31	68.78

In situations like this, the user may decide to toll other occupancy classes (e.g. S2) to improve the level of service of the tolled facilities.

Revenue Calculation

Revenue generated from the tolls can be calculated by multiplying the volumes the amount of toll. Volume and toll can be retrieved from the output networks from the latest iteration. Depending on which occupancy classes are tolled, the user must retrieve corresponding volumes from the network.

$$Revenue = \sum_{i=1}^{9} (\text{volume in period}_i * \text{toll in period}_i)$$

The above equation applied and aggregated over all segments should result in the total daily revenue across the region.

Conclusion

- Enhancements made to the model will allow the user to evaluate different road pricing scenarios.
- The user will have control over which sections of which roadway to toll, set the initial, minimum and maximum tolls for each segment.
- The user can also control different parameters that influence the model runtime, convergence criteria etc.
- The user can estimate revenues that can possibly be generated from different pricing scenarios.